MONTHLY WEATHER REVIEW

ALFRED J. HENRY, Editor

VOL. 52, No. 3
W. B. No. 831

MARCH, 1924

CLOSED MAY 3, 1924
ISSUED June 2, 1924

INVESTIGATION OF THE DUST CONTENT OF THE ATMOSPHERE

551.510.4

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[Weather Bureau, Washington, D. C., February 5, 1924]

SYNOPSIS

This paper summarizes observations with an Owen's dust counter furnished to the Weather Bureau by the Bureau of the Meteorological Section of the International Union of Geodesy and Geophysics, to promote international cooperation in a study of the dust content of the atmosphere. A similar instrument has been furnished to eleven other countries affiliated with the Union.

Most of the measurements by the Weather Bureau have been made at the American University, a thinly settled suburb to the northwest of the city of Washington. Some have been made at the central office of the Weather Bureau, and at the base and top of the Washington Monument, within the city. A few have been obtained in other cities, and interesting series have been obtained during airplane flights.

A summary of the results shows at the American University an average of about 850 particles per cubic centimeter in winter, and about 400 during the summer months. The extremes vary between about 4,000, on an unusually smoky day in January, 1923, and about 100 on unusually clear days throughout the year. A comparison of December, January, and February, 1922–23 with the same months in 1923–24 shows an excess of over 75 per cent in the number of dust particles in 1922–23, which is attributed to a general use of bituminous coal for heating purposes at that time on account of a shortage in the supply of anthracite.

During January, 1924, counts at the central office of the Weather Bureau gave more than double the number of particles found at the university, with a maximum of 6,046 particles per cubic centimeter. During February, probably on account of increased wind movement, the excess at the Weather Bureau was only 26 per cent.

A few measurements made in Chicago between September 24 and October 11, 1923, under average conditions, gave at the Federal Building a maximum of 7,180 particles per cubic centimeter, and at the University of Chicago a maximum of 4,800 particles.

The records obtained during airplane flights show a marked decrease in the dust content of the atmosphere above an altitude of 6,000 feet in August and 3,000 feet in October and November. Also a general decrease at all levels up to 7,000 feet after a rainstorm. There is also a slight excess at high levels on clear days, as compared with cloudy days due to the dust carried upward by convection currents.

A close relation is shown between the dust content of the atmosphere and the visibility both at the surface and from the altitude at which airplanes usually fly.

Object of the investigation.—At the meeting of the International Union of Geodesy and Geophysics that was held in Rome, Italy, in May, 1922, provision was made for an international study of the dust content of the atmosphere.

Several considerations make such a study worthy of international effort.

For example, visibility is an important factor in navigating both the sea and the air. Just what is the relation between visibility and atmospheric dustiness?

To what extent is the atmosphere of cities polluted by the incomplete combustion of fuel?

We know that after a violently explosive volcanic eruption the fine dust that is thrown to great heights sometimes floats in the atmosphere for several years before it finally falls to the ground. Just how widely is this dust distributed by the wind currents?

Will it be possible to detect the presence of dust that finds its way into our atmosphere from interplanetary space?

Apparatus.—As an aid to the solution of these problems, provision was made at Rome for the construction of 12 dust counters, of a kind designed by Dr. J. S. Owens of London, and for their distribution to metorological observatories in the different countries affiliated with the union. One of these counters was sent to the United States Weather Bureau, and has been in daily use since December, 1922.

The Owen's dust counter shown in Figure 1 (frontispiece), has three essential parts, as follows:

(1) A dampening chamber, A, which is simply a tube open at one end and lined with blotting paper which is thoroughly saturated with water.

(2) The other end of the tube is closed by a screw-threaded head, except for a narrow slot, B, 1 centimeter long; and above this slot is a bed for holding a microscope cover glass. When the end of the head is closed by the screwed plug, C, the three-claw spring presses upon the cover glass and holds it in place.

(3) A passageway leads from the space between the slot and the cover glass to an air pump, D, by means of which the air pressure above the slot may suddenly be greatly reduced.

This reduction in pressure accomplishes two things:

(*a*) It causes the air to pass at high velocity through the slot from the dampening chamber.

(*b*) The reduction in pressure as the air passes through the slot cools the already satuated air below its dewpoint and moisture is condensed upon the dust particles.

As a result of the above, the moisture-covered particles impinge upon the microscope cover glass at sufficient velocity to cause them to stick. If the cover glass is removed at once a line of moisture will be visible. This quickly evaporates, however, leaving an invisible line of dust particles..

The cover glass is next mounted on a microscope slide and examined. The first examination, for the purpose of locating the line of dust, is usually with a 16-mm. objective and an eyepiece magnifying 8 times, which gives a magnification of 125 diameters. To count the number of particles, a 1.8-mm. objective is used, with oil immersion, giving a magnification of 1,000 diameters. An eyepiece magnifying 12 times, with a 1.8 objective, giving a magnification of 1,500 diameters, is sometimes used.

With a magnification of 1,000 diameters dust particles 0.2 μ, or 0.0002 mm. in diameter may be seen.

Attention is invited to the difference in the results to be expected between dust determinations by this method

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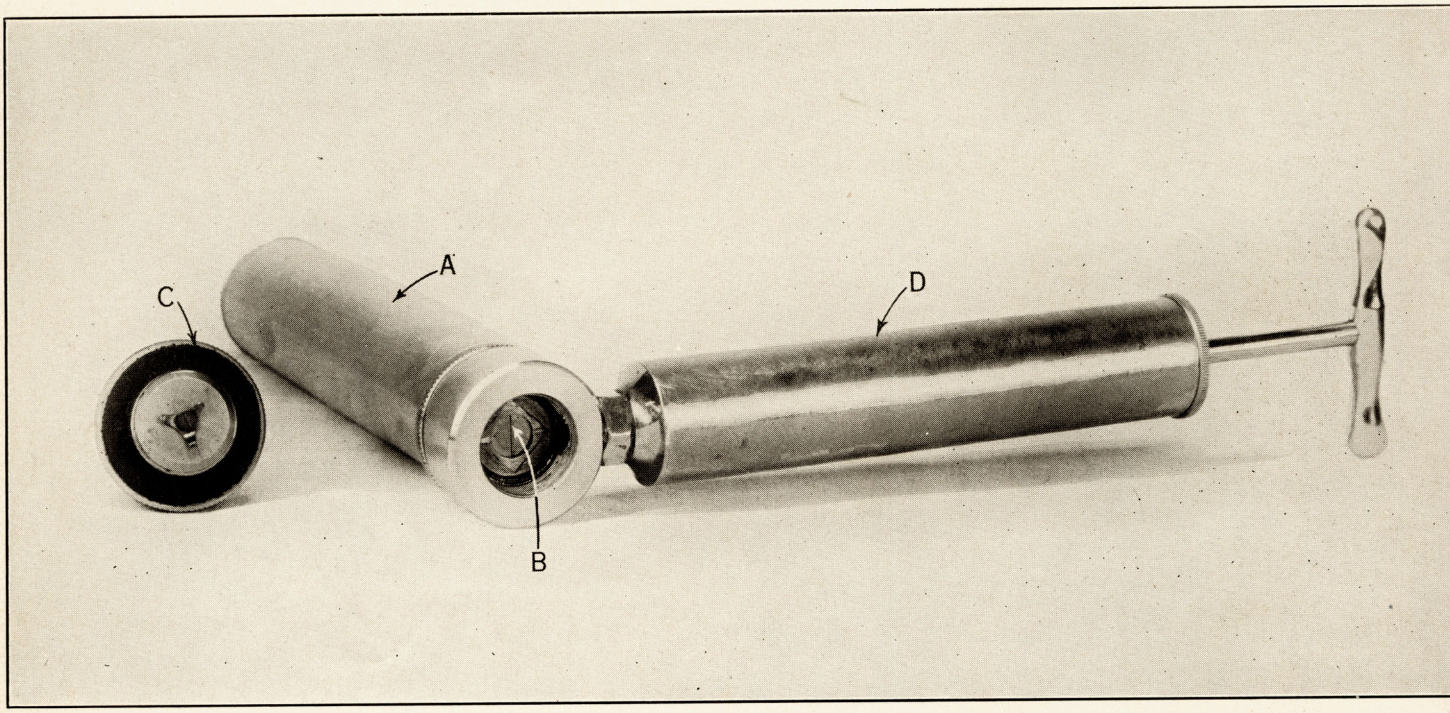

FIG. 1.—Owen's dust counter

and by that followed by Aitken and others. Aitken[1] counted the number of water drops formed when the air was cooled far below its dewpoint. Particles much too small to be seen under the microscope, and even molecules of hygroscopic gases, would serve as nuclei for condensation. Therefore he found many more particles per cubic centimeter than can be detected by the method employed in this research. Particles less in diameter than the wave length of ultra-violet light (0.0002 mm.), can not be made visible under the microscope.

The present research is concerned more particularly with the surface dust layer,[2] in which we live, and which contains most of the pollution resulting from human habitation. These particles are generally of sufficient size to be seen by the aid of a microscope.

Monthly averages of dust content of the atmosphere.—Figure 2 shows graphically the maximum, minimum, and mean number of dust particles per cubic centimeter, derived from the early morning dust counts at the American University. At once the seasonal variation, especially in the maximum number of particles, is apparent. Evidently the University is not outside the area of city smoke, especially when the wind is light with an easterly component. During the month of June the observations were made at the central office of the Weather Bureau, and the increased number of dust particles found is shown in the monthly mean and extremes.

TABLE 1.—*Summary of atmospheric dust counts, American University, 8 a. m.*

Number of observations	N	Humidity		Wind		Visibility
	Per c. c.	R. H.	e	Dir.	Vel.	
GROUP A. DECEMBER TO MARCH, INCLUSIVE						
		Per ct.	*mm.*		*m. p. h.*	*Miles*
5	102	47	2.85	NW	15	50
3	238	51	1.71	NW	17	50
2	156	66	4.66	NNW	6	30
3	350	46	1.46	NW	14	30
7	218	58	2.82	NW	10	17
4	469	51	3.77	SW	6	15
7	396	73	3.80	NW	9	10
5	735	73	6.12	SW	4	10
14	479	68	3.94		6	6
8	1,082	72	3.97		5	5
7	853	70	2.94		7	3
10	1,560	68	3.17		5	3
14	1,342	82	4.12		4	1
3	3,218	84	4.33		1	½
GROUP B. APRIL, MAY, JULY TO NOVEMBER, INCLUSIVE						
8	108	48	4.52	N	11	50
7	155	67	11.20	SW	7	30
10	303	73	12.89	SW	5	30
5	185	61	10.02	NW	8	20
6	578	61	9.04	W	6	16
15	232	72	9.30	NW	7	10
15	544	63	6.60	W	7	10
37	420	75	9.10	N	5	5.2
18	782	75	10.30		5	5.0
8	458	82	12.77		4	2.6
2	946	88	13.30		3.5	3.5
4	586	86	11.79		3.5	1

[1] Aitken, John. On improvements in the apparatus for counting the dust particles in the atmosphere. Proc. Royal Soc. Edinburg, 1889, vol. 16, p. 135.

[2] For a more complete discussion of the dust layers of the atmosphere, see a paper by one of us entitled "The Meteorological Aspect of the Smoke Problem." MO. WEATHER REV., Jan. 1914, 42: 29–35.

Correlation of number of dust particles and visibility.—In Table 1 the dust counts obtained at 8 a. m. at the university up to the end of 1923 only, have been summarized by groups. Group A contains all the counts made during the four cold months December, January, February, and March, the months when most of the coal for heating purposes is burned in Washington. Group B contains the counts made during the months April to November, inclusive, June excepted, when little or no coal is burned for heating purposes.

In these two groups further groupings are made in accordance with the limit of visibility, or the greatest distance at which large objects, such as mountains, hills, buildings, towers, etc., could be seen; and in these subgroups the arrangement is in accordance with the number of dust particles per cubic centimeter of space.

An examination of the averages of the subgroups in Table 1 shows a marked decrease in the limit of visibility with increase in the dustiness of the atmosphere, and indications that the limit of visibility also decreases with increase in the relative humidity.

Aitkin[3] has pointed out that the product of the number of dust particles per unit of space by the limit of visibility is a constant for equal depressions of the wet-bulb thermometer. No such simple relation is shown by the data of Table 1, however, nor should we expect it. The limit of visibility depends upon many factors, such as intensity of the illumination of the object seen, its color, the contrast between it and its background in illumination intensity and in color, light glare in the field of view, etc. Usually the background is the sky, and the presence of dust in the atmosphere decreases the illumination of the object, and also the color contrast between it and the sky, and increases the glare of light in the field of view. But the presence of clouds, and the position of the sun with reference to the object can also produce these same results.

Furthermore, at the American University local smoke may greatly increase the local dust content of the atmosphere above the average in the line of vision to mountains 30 to 50 miles distant toward the west and northwest.

The most distant object seen from the American University is the Blue Ridge Mountain Range, from 40 to 60 miles to the west, and from 1,500 to 3,000 feet in height, although probably under most favorable conditions the Massanutten Range, 70 miles distant, and 3,000 feet high, can be seen. Between the latter and Washington are the Bull Run Mountains, from 500 to 1,000 feet high, and 30 miles distant from Washington.

Unfortunately, until recently, we have not been able to identify different peaks of the Blue Ridge, and therefore when we have been able to see any part of it the limit of visibility has been recorded 50 miles.

To the northwest, Sugar Loaf Mountain, an isolated peak 1,280 feet high and 30 miles distant, is a prominent landmark. Nearer mountains and hills are not so prominent. Near by, the Arlington radio towers and the Washington Monument are prominent. The two points best determined as to distance and most favorably situated for observing are Sugar Loaf Mountain and the Arlington towers.

If we take the product of D, the limit of visibility, R. H., the relative humidity expressed as a per cent, and the maximum value of N, the number of particles per cubic centimeter, through which the point at distance D

[3] Aitken, John. Report on Atmospheric Dust. Trans. Royal Soc. Edin., 1902, v. 42 p. 485.

can be seen, or $C = D \times R.H. \times N$, we obtain roughly, $C = 480{,}000$, from which, $D = C/(N \times R.H.)$. Of course if N is small, this gives a value of D much larger than that observed, but not more discrepant than we would expect from the nature of the data. More refined methods of determining the limit of visibility are needed, and the values of N should be free from local influences.

Diurnal variation in the number of dust particles.—On international days, as designated by the International Committee for the Exploration of the High Atmosphere, and on some others, dust counts were made at noon, or later, as well as at 8 a. m., the results sometimes showing an increase in N during the day and sometimes a decrease. The means for 27 days gives 537 for the average of the a. m. observations and 480 for the average of observations taken at noon or later.

Abnormal variations are sometimes observed. For example, on December 4, 1923, observations at 8 a. m., 10 a. m., noon, 2 p. m., and 4 p. m., gave for N, 2,341, 1,713, 383, 690, and 619, respectively. In this case a light wind from the north with fog shifted by way of east to a fresh wind from the south. Again, on December 12, 1923, determinations at 8 a. m., 10 a. m., and noon, gave for N, 225, 1,427, and 998, respectively. A light southwest wind shifted to the east, bringing city smoke over the university, and then shifted back to south.

Comparison between the dustiness at the American University and in the city.—From May 29 to July 2, inclusive, except on June 12, 13, and 14, the dust counts were made at the central office of the Weather Bureau. The mean of 24 determinations is 522, which is 33 per cent greater than the average for the months of May, and July to October, inclusive.

From the latter part of December, 1923, to March 20, 1924, measurements were made at both the university and the Weather Bureau. The means and extremes for the two stations are as follows:

TABLE 2

Month	Maximum			Minimum			Mean		
	Dec.-Jan.	Feb.	Mar.	Dec.-Jan.	Feb.	Mar.	Dec.-Jan.	Feb.	Mar.
American University	2,403	1,964	1,280	124	97	76	761	533	453
Weather Bureau	6,046	2,546	1,324	248	129	128	1,831	670	603

Comparisons between the dustiness in 1922-23 and 1923-24.—In Figure 2, a decrease in the number of dust particles in the atmosphere at the University is shown in the means and also in the extremes for December to February, 1923-24, as compared with the same months in 1922-23, with the exception of the maximum for December. These figures are significant, in view of the fact that the records of the Coal Merchants' Board of Trade show that from April to December, inclusive, 1922 ,there were received in Washington 218,850 tons of anthracite and 607,047 tons of bituminous coal, or about 2.8 tons of bituminous coal to each ton of anthracite. In January, 1923, 64,126 tons of anthracite and 132,893 tons of bituminous coal were received, or at the rate of 2.1 tons of bituminous coal to each ton of anthracite. From April to December, 1923, and also in January, 1924, 1.8 tons of bituminous coal were received for each ton of anthracite, the total receipts for the whole period being 782,185 tons of bituminous coal and 439.515 tons of anthracite.

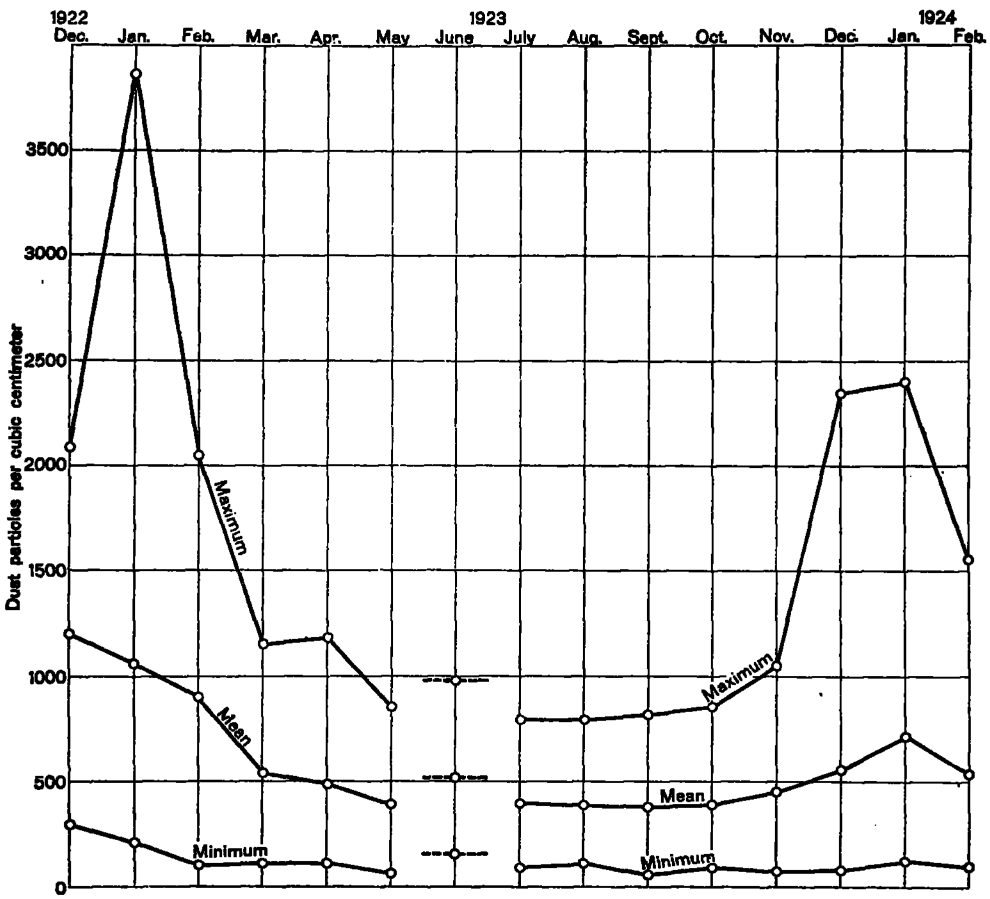

FIG. 2.—Monthly extremes and means of dust content of the atmosphere at the American University, District of Columbia

The increased receipt of coal in 1923–24 as compared with 1922–23 is, of course, explained by the fact that on account of strikes but little coal was stored during the summer of 1922, while in 1923 storing was general. On account of the shortage in the supply of anthracite coal the use of a certain percentage of bituminous coal in heating dwellings was compulsory during the winter of 1922–23· Inefficient stoking on the part of many householders as well as the increased use of bituminous coal will account for this increased smokiness of the air. Furthermore, during December and January, 1922–23, atmospheric dust records showed a greater percentage of soot, or unconsumed carbon, than in December and January, 1923–24. However, the unusually mild temperatures in December, 1923, averaging 8° F. above the normal, no doubt contributed to the relative clearness of the atmosphere during that month.

The decrease in the monthly mean dust content of the atmosphere from December to March, in 1922–23, as shown in Figure 2, and especially the decrease at the Weather Bureau from January to February, 1924, as shown in Table 2, is undoubtedly partially due to the increased wind movement for the late months of winter, as shown in Table 3.

TABLE 3.—*Average hourly wind velocity for Washington, D. C.*

[Miles per hour]

	December	January	February	March
1922–23	5.9	8.1	8.2	9.1
1923–24	5.5	7.5	8.2	10.0

The decrease in the number of mornings with light winds as the winter season advances is also a factor.

Variation in the number of dust particles with height above ground.—In Table 4 are comparisons of readings at the American University, and at the top and bottom of the Washington Monument, the top being 500 feet above its base.

Generally the densest smoke is at the base of the monument, and there is more at the top than at the American University. January 8 and 18, 1923, are exceptions. On the 8th most of the smoke was below the 500-foot level, and on the 18th the smoke was much denser at the 500-foot level than at the surface. The relative humidity was 100 per cent on the 8th and 54 on the morning of the 18th. Light snow fell shortly before noon on the 18th. The wind was blowing about 6 miles per hour from the west on the 8th, and about 10 miles from the southwest on the 18th.

TABLE 4.—*Comparison of dust determinations at the American University and the Washington Monument*

	American University	Monument		Remarks
		Base	Top	
1922				
Dec. 26	2,080	2,977	2,616	Dense fog.
1923				
Jan. 5	1,274	2,625	2,560	Visibility 2 miles at base, 3 miles at top.
Jan. 8	878	1,496	259	Haze and smoke at base, clear at top.
Jan. 10	250	676	620	Very clear, visibility 50 miles.
Jan. 13	827	1,209	958	Top only of Arlington towers visible (5 miles).
Jan. 18	515	522	1,230	Visibility 5 miles.
Averages	947	1,584	1,340	

Dust counts from airplanes.—During the winter of 1922 to 1923 observations were confined to the American University and the few taken at the Washington Monument. It soon became evident, however, that like practically all meteorological problems, the examination of the dust content of the atmosphere should be extended to high altitudes in the free air. Arrangements were therefore made by the Chief of the Weather Bureau with the Chief of the Army Air Service for the cooperation of the aviators at Bolling Field in this work. Bolling Field is about 7 miles southeast of the university, on the river front just below the city of Washington.

Two preliminary flights in April demonstrated that the dust counter furnished from London was not adapted to airplane work. Too many strokes of the pump were necessary to obtain a legible record on the cover-glass, and great difficulty was experienced in changing cover-glasses between observations at the different levels on account of the high wind to which the observer was exposed. Therefore, a dust counter having a pump with five times the capacity of the London instrument and with 10 duplicate heads in which cover-glasses could be secured before flights, was constructed in the Weather Bureau machine shop. These 10 heads were secured in a box conveniently arranged for handling. Then while the plane was changing its level 500 or 1,000 feet it was only necessary for the observer to detach the pump and dampening chamber from one head and attach them to another. The end of the dampening chamber slips into the head below the slot and is held by friction. These changes can be made in less than a minute, an important consideration at levels where the temperature is low.

An examination of the dust records obtained on the April flights showed that they were vitiated by smoke from the exhaust of the airplane engine. Therefore a De Haviland plane was provided with pipes to carry the smoke back of the rear cockpit, which is occupied by the observer. When the plane reached a height at which a dust record was desired, the aviator usually throttled down his engine and coasted during the fraction of a minute necessary to obtain a record. Smoke from the engine was therefore practically eliminated from the records, except in a few cases where the aviator had not learned to coordinate his movements exactly with the observer's program.

The observational program was arranged with the pilot before leaving the ground, as communication was difficult during flight. During August records were usually obtained at the 2,000, 4,000, 6,000, 8,000, and 10,000 foot levels during the ascent, and at the 9,000, 7,000, 5,000, 3,000, and 1,000 foot levels during the descent. It was found, however, that after the dust counter had become cooled to a low temperature during the ascent it warmed up only slowly during the rapid descent. Pumping warm air through the cold instrument had the effect of condensing water on the cover-glass as well as on the dust particles. Before some of the records could be counted it was necessary to place them in a box that was heated to a moderately high temperature by an electric lamp for a considerable period of time. Not all the records were made legible in this way, and the means of Table 5 indicate that all records so treated are of doubtful value. During October and November all the records were obtained during the ascent.

TABLE 5.—*Dust records from airplanes*

AUGUST SERIES

Altitudes / Dates	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
A. M.											
Aug. 16	251	......	384	......	282	343	172	141	96	72	48
20	372	371	376	404	466	450	366	151	131	70	55
21	292	210	233	269	304	144	89	50	39	32	25
24	200	183	228	189	157	139	180	84	70	......	59
29	268	200	137	121	105	159	150	93	88	68	52
Means	277	241	272	246	263	247	191	104	85	60	48
P. M.											
Aug. 15	300	323	504	475	445	394	376	......	......	......	89
16	157	......	292	......	404	......	273	......	81	......	55
21	251	198	246	233	211	193	191	131	89	50	50
24	221	146	209	177	170	137	159	111	74	27	44
Means	232	222	313	295	308	241	250	121	81	38	60

OCTOBER-NOVEMBER SERIES

Altitudes / Dates	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Oct. 25	445	282	......	343	177	139	139	106	75	80	43
26	298	355	379	302	208	139	116	112	73	65	55
29	522	361	222	188	159	84	73	69	53	39	29
30	471	386	345	165	106	55	43	47	37	31	31
31	220	263	277	......	200	177	100	94	78	59	55
Nov. 2	322	381	322	261	139	75	......	......	......	......	......
3	222	129	145	151	110	59	......	......	......	......	......
Means	357	308	282	235	157	104	94	86	63	55	43

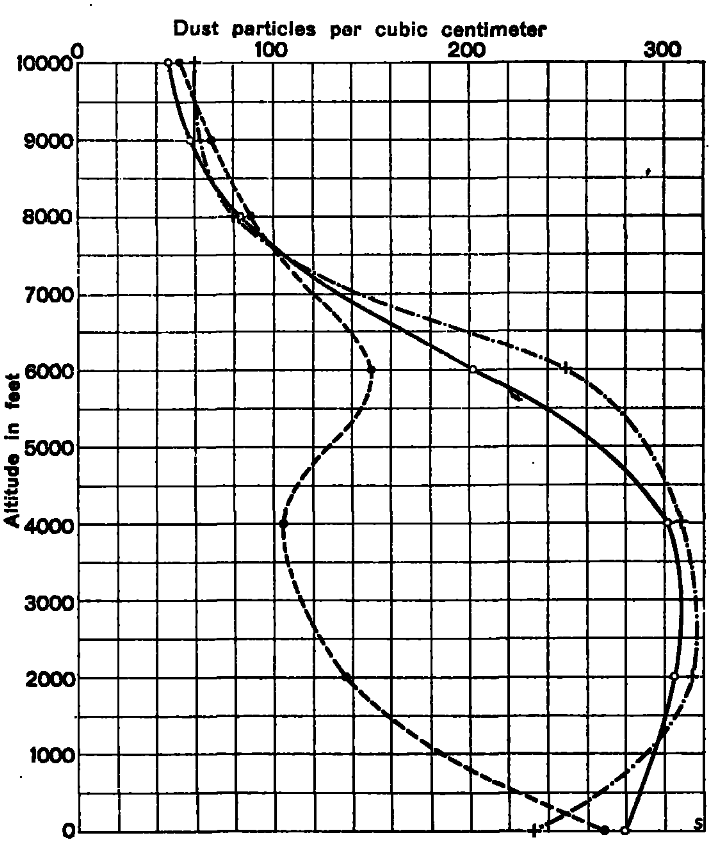

FIG. 3.—Atmospheric dust content determinations during airplane flights, August, 1923. ○, clear sky, a. m.; ✚, clear sky, p. m.; ●, cloudy sky after rain.

The initial flights in April were to 12,000 feet elevation. In August and October, 10,000 feet was the highest elevation reached, except that one flight was made to 14,000 feet to observe clouds. On November 2 and 3, on account of the extreme cold, the flights were to 5,000 feet only, and dust counts were made at 500-foot intervals.

The dust records obtained during airplane flights are summarized in Table 5, and mean results are shown graphically in Figures 3 and 4. Only the measurements obtained during the ascent of the plane have been used in constructing the curves of these figures.

From Figure 3 it will be seen that with a clear sky in the morning (○) there is more dust near the ground and less between 2,000 and 7,000 feet than in the afternoon (+). The increase at high levels later in the day is undoubtedly due to convection. The records obtained on August 29 (●) show the cleansing effect of the rainstorm of the previous night.

From Figures 3 and 4 we note the difference in distribution of the dust in the atmosphere on clear (○) and on cloudy (●) mornings. Often with clear skies there is a noticeable increase in the dust content with elevation up to about 2,000 to 5,000 feet that must be attributed to the effect of vertical convection currents. Visual observations confirm this increase. Thus, on August 20, the observer's notes state: "The ground visibility was very good, and objects were seen with distinctness; but aloft (5,000 feet) the sky appeared to be filled with dense haze."

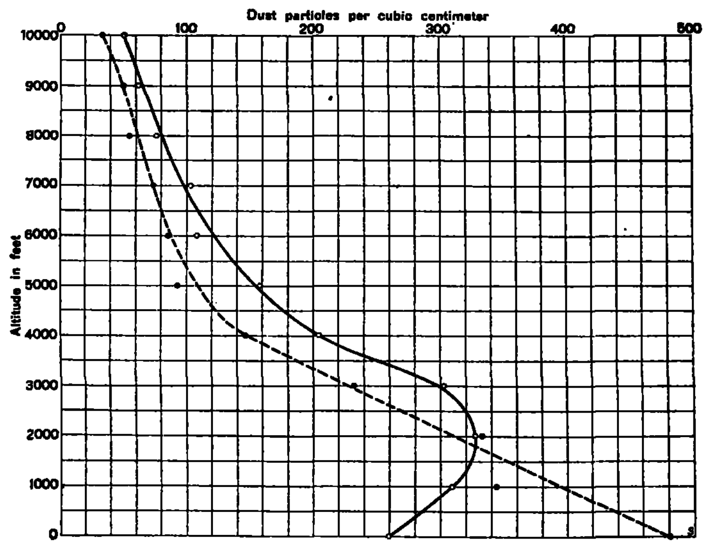

FIG. 4.—Atmospheric dust content determinations during airplane flights, October to November, 1923. ○, clear sky, a. m.; ●, cloudy sky, a. m.

The curves of Figures 3 and 4 may be compared with the curves of Figure 19, p. 49, Monographs on the Theory of Photography from the Research Laboratory of the Eastman Kodak Co. No. 4, Aerial haze and its effect on photography from the air. In this latter figure the curve for January 14, 1919, a. m. (logarithmic type), showing a diminishing rate of increase of haze with increase in altitude, is in agreement with the general decrease in the dust content of the atmosphere with altitude. The remaining curves of this figure (straight line and parabolic types) show the influence of moisture and perhaps other factors as well as dust in the formation of haze.

The time required for a flight has varied from 17 minutes to about one hour. During this time in August the observer was subjected to temperature changes from perhaps 90° F. to 40° F., and in October and November from about 70° F. to 20° F., and at the same time to atmospheric pressure changes from about 30 inches to 20 inches, and to changes the reverse of these. Suitable clothing is sufficient protection from cold except for the hands, but the rapid pressure change is not so easily guarded against. Unpleasant results, such as ringing in the ears, temporary deafness, nausea, etc., sometimes follow.

Full compensation for these disagreeable features is afforded, however, by the wonderful optical phenomena observed above the clouds. At an altitude of 10,000 feet the sky is a deep blue quite up to the edge of the sun's disk. Looking away from the sun a fourfold color effect will be seen. In a layer of purple haze float cumulus clouds, their bases orange or golden yellow, while their summits, above the haze, are a dazzling white against the deep blue of the sky. On days when the upper limit of the haze is well defined the orange bases of the clouds will not be visible in the dark gray haze, while if the sky is very clear, near the horizon it will take on a distinctly greenish shade.

The shadow of one's plane on the clouds below, fringed in spectral colors, is always a beautiful sight.

For pastime, the avaitor sometimes dissipates a small cloud by repeatedly flying through it, mixing its moisture-laden air with drier air, and breaking up the vertical convection current that sustained it.

On August 29 a large cumulus cloud was encountered at about the 3,000-foot level. The aviator drove his plane into it from different sides, going through horizontally, upward and downward. The most noteworthy phenomenon, outside the general bumpiness, was the distinct shock experienced just before entering the cloud from the side, undoubedly caused by a downward current of air.

Besides obtaining dust records, notes were made on the limits of visibility, i. e., the distance from a point directly below the plane to which objects like rivers or lakes, buildings or mountains, could be seen, and also the approximate altitude of the upper limit of the haze layer or layers. Neither of these observations is easily made without considerable experience, the first because an inexperienced observer is never quite sure of the exact direction of *down*, and the second because the boundary of haze layers generally does not seem to be sharply defined.

In Table 6 are summarized the observer's notes on the limits of visibility, and this table is followed by notes on the upper limit of haze, the cloudiness, etc. From these notes it is evident that cloudiness, even in its incipient stage, plays a most important rôle in the limit of visibility from the air. It is to be noted, however, that on August 21 and 29, and October 30, when the visibility from 10,000 feet was unusually good, the dust content of the atmosphere was less than the average. This is not true of October 25, however, with good visibility recorded at all levels.

TABLE 6.—*Visibility, in miles, of land and water surfaces*

Date	Altitude (feet)										
	0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
Aug. 15, p. m.	10	20				15		10			
16, a. m.	10	25	10					5			
16 p. m.	10	25			10			10		15	
20, a. m.	10	10	10	10	10	15	10	10	10	10	10
21, a. m.	8	25	10	10	10	10	10	50-60	50-60	50-60	50-60
21, p. m.	10		5W, 10E.						10 land, 20 water.		
24, a. m.	5	10				20 land, 25 water.					10
24, p. m.		25	Low on account of clouds.								
29, a. m.	3	10									60
Oct. 25, a. m.	5	20	25	25	25	25			60	60	60
26, a. m.	5								40 land, 50 river.		
29, a. m.	3										15[1]
30, a. m.	Poor.										100
31, a. m.	8					20					
Nov. 2, a. m.	10	15				20					
3, a. m.	8					20					

[1] At 14,000 feet.

NOTES ON THE UPPER LIMIT OF HAZE, CLOUDINESS, ETC.

August 15. At 7,000 feet passed through cumulus clouds. Very bumpy. At 10,000 feet the upper limit of the haze was sharply defined. Opposite the sun it appeared as a black line that cut off the view of everything below it, including cumulus clouds.

August 16, a. m. Visibility diminished at 8,000 feet by incipient clouds. Cumulus bases cut off by haze, which was very dark away from sun but whitish under the sun.

August 16, p. m. Haze diminishing in intensity above 7,500 feet.

August 20, a. m. Strato-cumulus merging into alto-cumulus slightly above 7,000 feet.

August 21, a. m. Low clouds diminished visibility. Fr-Cu. at 1,000 feet, cumulus clouds from 2,000 to 4,000 feet.

August 21, p. m. Upper limit of haze not so well defined as usual. To the east it appeared to be in four separate levels, with the boundaries rather wavy in outline.

August 24, a. m. Apparent upper limit of haze 6,000 feet at time of ascent, but about 200 feet higher at time of descent.

August 29. Low clouds made visibility poor until plane passed above them.

October 29. Entered an A. Cu. cloud at 12,000 feet, and passed out of it at 13,500 feet. Ice formed on struts and wings of plane as soon as cloud was entered, but observed the Brocken Specter and fog-bow when looking down upon the cloud from the 14,000-foot level, which indicates that it was made up of water drops, although the temperature was far below freezing. No bumps experienced.

During October and November the time that the plane was in the air was so short that it was impossible to make extended notes.

Character of the dust particles.—Atmospheric dust consists of particles so small that only a few of the larger ones can be examined by the usual petrographic methods. Occasionally an examination of the colloidal material found in the deposit from rain and snow fall has given an indication of the character of the dust from which it was formed. (See Pl. I, A.) In general, it can be stated that finely divided mineral matter and loess make up the larger part of the particles. A few diatoms, spores, pollen, crystals of calcite and gypsum, and in winter various products of combustion, have been identified. (See Pl. I, B.) We would expect to find calcite in the dust from building operations. Gypsum may result from the reaction of sulphuric acid and calcium carbonate; and since it has been identified only on records obtained at the Washington Monument, it is thought that the above reaction may be the result of smoke from a near-by stack upon the marble shaft.

On August 3 a peculiar egg-shaped opalescent particle was first noticed. It was found at all elevations up to 10,000 feet, although there were few at high levels. They were last observed on November 23. After many tests they were finally identified as spores, but the variety was not determined until after an examination of similar spores that had been found in the air near London, England, was made at Kew Gardens. A detailed description of these spores is given in a paper in this REVIEW (p. 139) by Sir Napier Shaw. (See also Pl. II and III, figs. 1–11.)

In general it can be stated that the average size of the particles decreases with the altitude at which they are collected. It is roughly estimated that the average diameter of the particles collected at the surface is about four times that of those collected at 10,000 feet. Therefore, since the volume varies with the cube of the diameter the ratio of the number of the particles per unit of space would have to be multiplied by 64 to obtain the ratio of the volume of the particles at these two levels.

Dust counts away from Washington.—A dust record obtained at the Central Park Observatory, New York, on July 13, 1923, gave 723 dust particles per cubic centimeter, and a record obtained at Long Island City, a

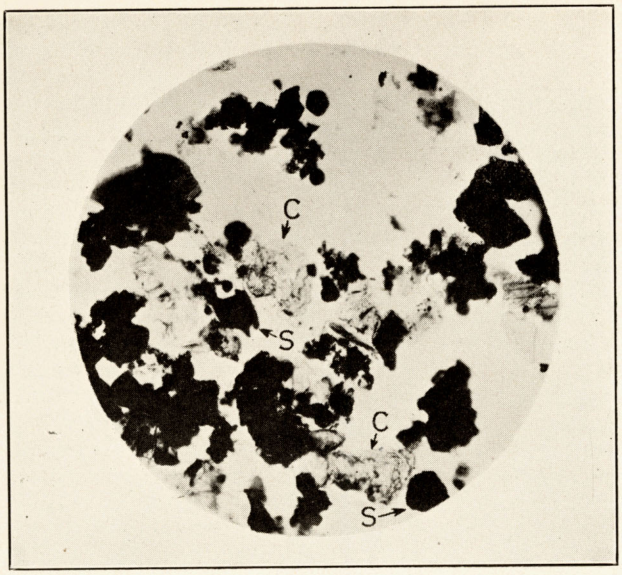

PLATE I, A.—Photomicrograph of sediment from melted snow. S, soot, from smoke; C, colloidal material

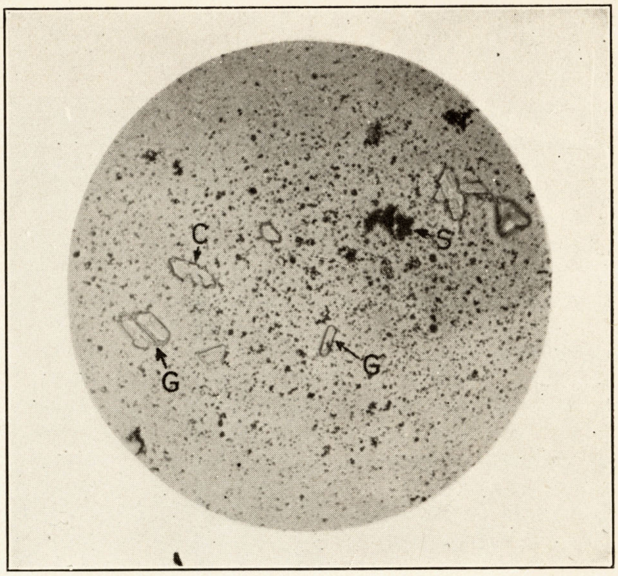

PLATE I, B.—Photomicrograph of dust record obtained at the Washington Monument. C, calcite; G, gypsum; S, soot from smoke

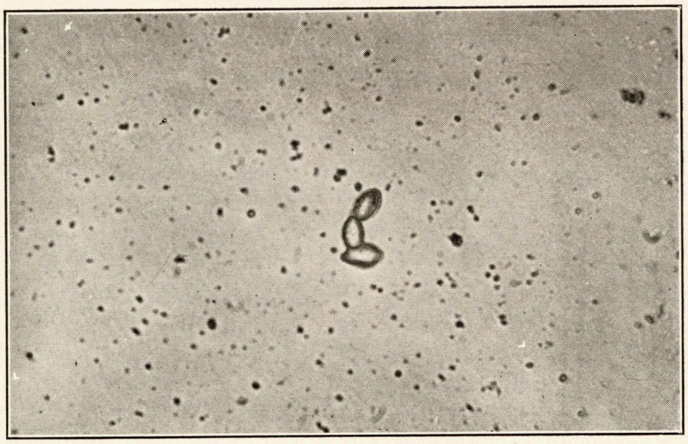

FIG. 1.—October 17, 1923, 8:30 a. m.

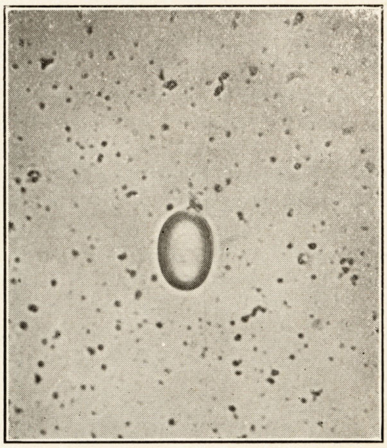

FIG. 2.—October 17, 1923, 9 a. m. Magnification 1,000 diameters

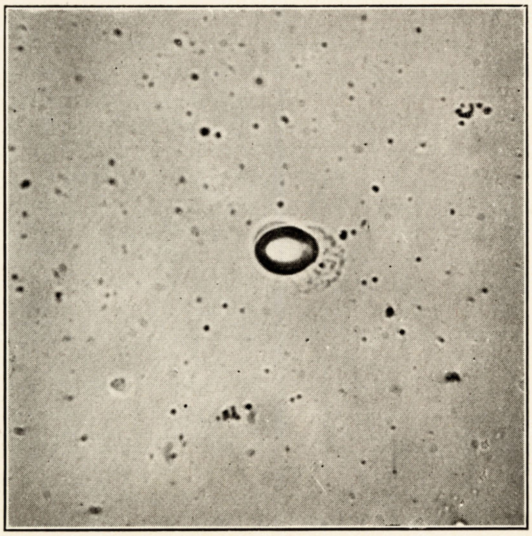

FIG. 3.—October 19, 1923, 8 a. m. Magnification 1,000 diameters. The large organic body is surrounded by a drop of water

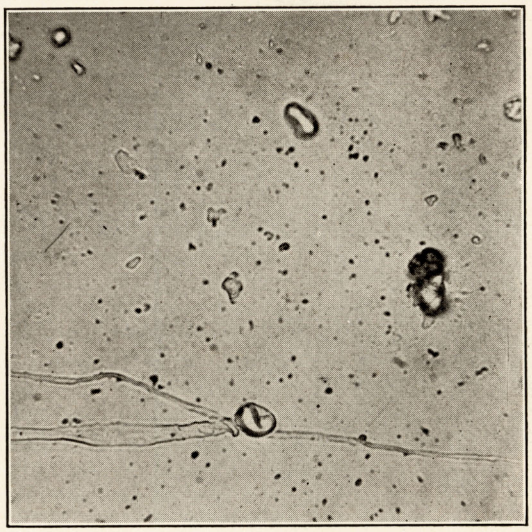

FIG. 4.—October 19, 1923, 8 a. m. Magnification 1,000 diameters. Note fungal hyphæ (?) attached to a body

PLATE II.—Photographs of sporelike bodies found in the atmosphere. Taken at Cheam, England

Fig. 5.—From the air at Cheam, October 19, 1923, 8 a. m. Magnification 1,000 diameters

Fig. 6.—From the air at Cheam, October 19, 1923, 9 a. m. Magnification 1,000 diameters

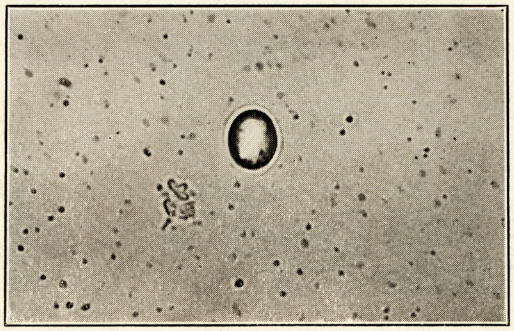

Fig. 7.—From the air at Cheam, October 19, 1923, 9 a. m. Magnification 1,000 diameters

Fig. 8.—From the air at South Kensington, October 20, 1923, 3 p. m. Magnification 1,000 diameters

Fig. 9

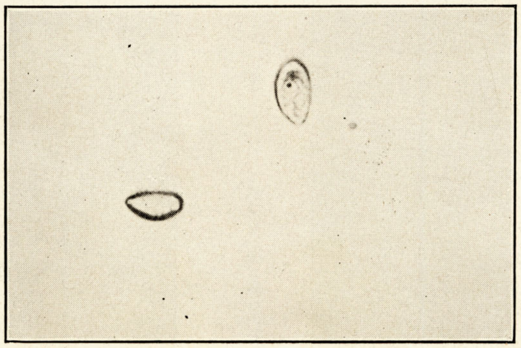

Fig. 10

Fig. 11

Figs. 9, 10, and 11.—Obtained from fallen leaves shaken above a microscope slide, November 3, 1923. Magnification 1,000 diameters

Plate III.—Photographs of sporelike bodies manufacturing center, on the following day, gave 2,036 particles per cubic centimeter.

On September 24 and 25, at about 10 a. m., and on October 11 at 4 p. m., dust records obtained at the Federal Building, in the loop district, Chicago, Ill., gave 6,070, 7,180, and 4,530 particles per cubic centimeter, respectively. Records obtained at Chicago University, in a residence section of the city, at about 8 a. m. on September 24, 25, 26, and at 10 a. m. on October 10, gave 4,800, 3,830, 3,110, and 1,920 particles per cubic centimeter, respectively. On none of these days was the smoke particularly dense for Chicago. Nevertheless the two morning measurements at the Federal Building show a greater number of particles than has ever been found in Washington.

Acknowledgments.—We take this opportunity of expressing our grateful appreciation of the hearty cooperation extended to us, in the execution of the investigations at high altitudes, by Lieut. B. J. Sherry, Meteorological Office, Lieut. L. J. Maitland, operations officer, Lieut. St. Clair Streett, model control officer, and the various other officers from Bolling Field who piloted planes from which observations were made. Without such cooperation, given in a spirit that indicated an appreciation of the problems to be solved, the work could not have been accomplished.

SUMMARY

Surface visibility is a poor criterion of visibility at the ordinary levels of air navigation. After leaving the ground on a morning when objects could be seen at a distance of 20 miles or more, upon reaching a height of 3,000 feet it appeared as though the plane were flying in dense smoke and the visibility decreased to 10 miles.

On the other hand, on October 30, with light fog and poor seeing at the surface, at 10,000 feet the visibility was 100 miles.

The visibility from the air is greatly diminished by clouds even in the incipient form.

The dust content of the air in the city of Washington was markedly increased during the winter of 1922–23 by the enforced use of bituminous coal in heating private dwellings.

While mineral matter, loess, spores, diatoms, and pollen have been identified in atmospheric dust, and also transparent spherical particles of a glassy nature, probably from local furnaces, no dust that appeared to be of volcanic or cosmical origin has been observed.

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NOTE ON ORGANIC BODIES FOUND IN THE AIR OF WASHINGTON AND LONDON

By SIR NAPIER SHAW, F. R. S., Chairman of the Advisory Committee on Atmospheric Pollution, London

It was reported on August 25 last by Dr. H. H. Kimball of the Weather Bureau, United States Department of Agriculture, that during the whole of August unusual and comparatively large opalescent particles had been encountered in samples of dust taken in Washington by means of the jet instrument supplied to him through the International Union of Geophysics and Geodesy. These particles had not yet been identified. They were present in large numbers in records taken both on the ground and from an airplane.

At the beginning of September a specimen slide containing some of the particles was received in London from Doctor Kimball. The particles had the appearance of definitely organic structures, some unicellular and some bicellular; they were usually clear, turgid and spherical or oval but sometimes irregular, with as many as nine short but well-defined protuberances. No nuclei could be seen in the cells.

Drawings of the best defined particles were made and these were exhibited by Doctor Owens at the soirée of the British Association in Liverpool.

Somewhat similar particles evidently of organic origin, considered to be pollen grains or spores, had been obtained occasionally by Doctor Owens in records taken in this country at a rural station. The numbers were, however, always very small and no such particles had ever been noticed in records of suspended matter in London.

On October 10, 1923, a record of 1,000 c. c. taken at South Kensington in the usual way was found to contain two large bodies identical in appearance with some of the opalescent particles in the American record. These were single oval cells filled with finely granular matter, each 6 microns long by 3.75 microns wide, with a well-defined papilla at one extremity. The cell wall appeared rough and pitted, and was appreciably thinner at the top of the papilla than at other points. Since this date particles of definite structure have been found in a large number of records.

On October 11 at South Kensington, the bodies were present to the extent of about two per liter. A record taken at 10:15 a. m. contained a perfectly clear spherical body 5 microns in diameter with smooth surface, a similar body with rough and crinkled wall, and a cigar-shaped structure divided in the middle and containing two definite oval cells. The latter was not turgid but bent over in the middle.

When water was introduced under the cover slip, the cigar-shaped particle immediately became turgid and apparently split open near one end. The length of the extended particle was 10.8 microns. The center partition dividing the body into two equal cells was well defined.

A small quantity of a solution of gentian violet was introduced under the cover slip. The cigar-shaped particle and the sphere with the rough wall at once took up the stain and became almost black, but the clear sphere was unaffected.

Further records were found to contain similar oval and spindle-shaped particles, which readily took up the stain when mounted in blue glycerin jelly.

A number of records have since been taken at different hours, from which it is concluded that the organic particles have not been present at all times of the day in London. For instance, records taken in Bloomsbury on Sunday, October 14, at 1 a. m. and at 12:15 p. m. contained no definite organic structures, but many square and hexagonal crystals, some of which were quite well formed.

Again, at 8:30 a. m. on October 17, records were taken simultaneously at Cheam, near London (fig. 1, Pl. II) and at London, in Bloomsbury. The record at Cheam contained at least 20 definitely organic particles per liter, generally oval in shape and up to 12 microns in length, together with approximately 630 smoke particles per c. c. whereas the London record contained only 5 or 6 such bodies, and all less than 5 microns in length. The number of smoke particles shown by the London record was approximately 5,000 c. c. The organic particles from the air of Cheam on this occasion were of particular interest. Three roughly oval cells, each about 4 microns